MERRIMACK VILLAGE DAM, SOUHEGAN RIVER

MERRIMACK VILLAGE, NEW HAMPSHIRE

SEDIMENT TRANSPORT STUDY

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Stream Conditions

Hydraulic analyses and visual observations indicate sedimentation is occurring as a result of the backwater influence behind the Merrimack Village Dam. Sediment deposition of as much as 8 feet has occurred in the impoundment. The total estimated volume of sediment behind the dam is 81,000 cubic yards. This volume was calculated based on 8 cross-sections and probing of sediments within the impoundment, extending 1600 feet upstream of the dam.

Above the Merrimack Village Impoundment, aquatic habit appears able to support fish with quality riparian corridor habitat as buffer for in-stream habitat. Enough shade exists to maintain optimal water temperatures, and particle sizes large enough (coarse sands, gravel, cobble, and boulders) to create turbulence sufficient to maintain dissolved oxygen levels. Signs of eutrophication such as brown algae and excessive submerged aquatic vegetation are not evident in the upstream reaches from the dam.

Instream habitat within Merrimack Village Dam impoundment suffers due to low water velocity, sedimentation, lack of shade, and a wide and shallow reach. The long residence time of water in the impoundment likely contributes to elevated water temperatures and low dissolved oxygen.

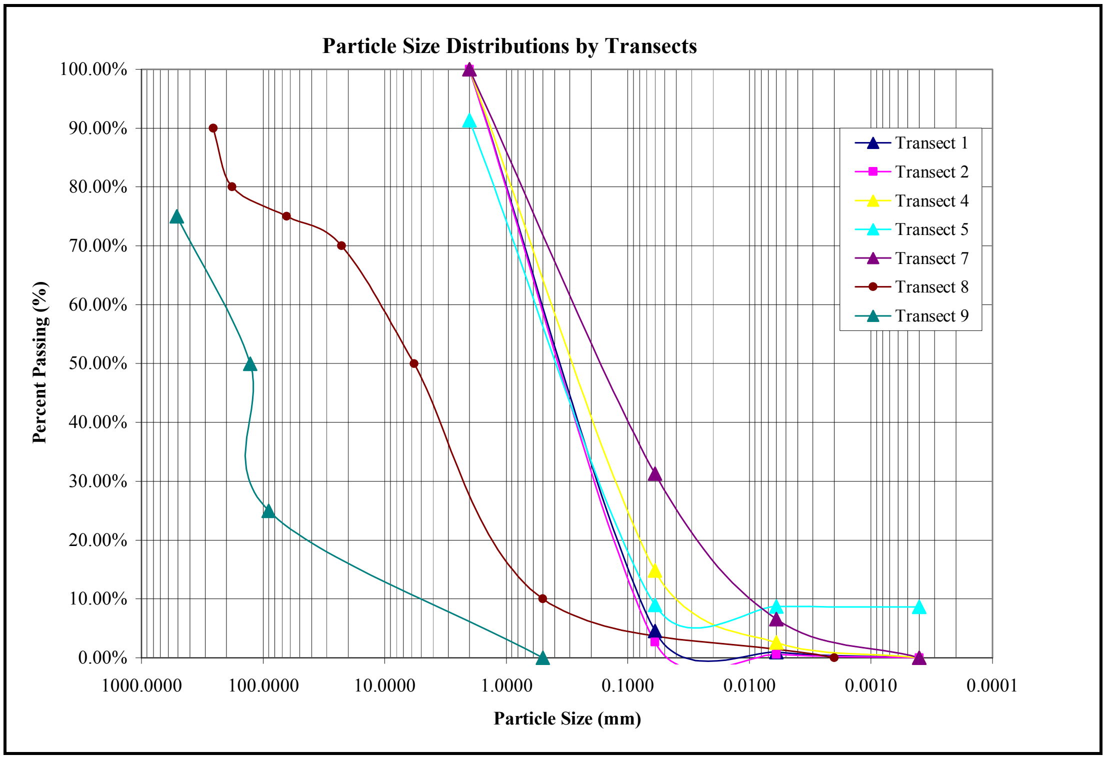
Samples indicate sedimentation of relatively uniform sand-size particles is occurring within the Merrimack Village Dam impoundment. The particle size distributions, determined by both sediment samples and pebble counts for the surveyed cross-sections, are presented below. Station 22 represents conditions above and below the impoundment with shallow depth to bedrock.

***Table 1*: Particle Size Distributions by Station and Transect**

Station	Transect	D15 (mm)	D50 (mm)	D85 (mm)
	1	0.1	0.37	1.1
18.3	2	0.11	0.37	1.1
19.3	4	0.06	0.28	1.1
19.6	5	0.09	0.37	1.6
20.6	7	0.018	0.17	0.9
	8	0.9	5.7	210
22	9	17	140	500

The alternative of channel restoration and dam removal will alter the current flow regime causing the sediment deposition and low channel velocities within Merrimack Village Dam impoundment. Channel aggradation has occurred within the impoundment because of the low velocities and high residence times of the water at low flow conditions. Post-dam removal channel geometry and bedslope will be such that sediment transport continuity will be restored and eliminate the need for maintenance dredging of the impoundment. The resulting sediment transport will continue downstream to the confluence of the Souhegan and the Merrimack River. Post-dam removal channel velocities will move larger particles downstream into the location of the current impoundment. The gradual increase in abundance of these larger particles will slowly stabilize the underlying sediments through channel armoring.

Figure 1: **Cumulative Distributions Curves by Transect**



Determining appropriate bankfull channel dimensions is critical for establishing a geomorphologically stable channel. It is at this flow that much of the channel formation and erosion occurs. Larger flows above bankfull have similar channel forming functions, but are generally stabilized in overbank conditions where vegetative stabilization, a thick boundary layer, and high roughness play a large role. Plus, these larger flows are much less frequent than bankfull flows. For a large variety of rivers throughout North America, bankfull channel cross section geometry has been shown to correspond with a discharge that has a recurrence interval of approximately 1-5 years in the annual flood series, depending on the region and climate (Dunne and Leopold, 1978). Data for the 2-year recurrence interval discharge (Q2) was modeled for the project reach. A representative low flow (Qlow), a mean annual flow (Qmean), Q2, Q10, and Q100 were used to evaluate sediment transport and particle stability. Inspection of topographic maps of the Souhegan River, in combination with an understanding of the regional physiography and stream channel patterns, guided the sediment transport and management assessment.

Channel and Particle Stability

Based on particle size distribution and model-derived hydraulic parameters, particle stability analyses were performed. Stability analyses are consistent with field observations that indicate that sedimentation of particles from cobbles down to fines is occurring within the impoundment thereby disrupting sediment transport continuity and resulting in channel aggradation above the dam. Particle stability was determined by shear stress assessment per ASCE Manual 54 and EM 1110-2-1418. The Shield's parameter was used to determine the particle size that will experience incipient motion (Simons et al, 1982).

Equation 1

$$D_s = \frac{\tau_c}{0.047(\gamma_s - \gamma_w)}$$

D_s=particle size at incipient motion (mm)
$\tau_c = \gamma RS$=critical shear stress (lb/ft^2)
γ_s=specific weight of sediment (lb/ft^3)
γ_w=specific weight of water (lb/ft^3)

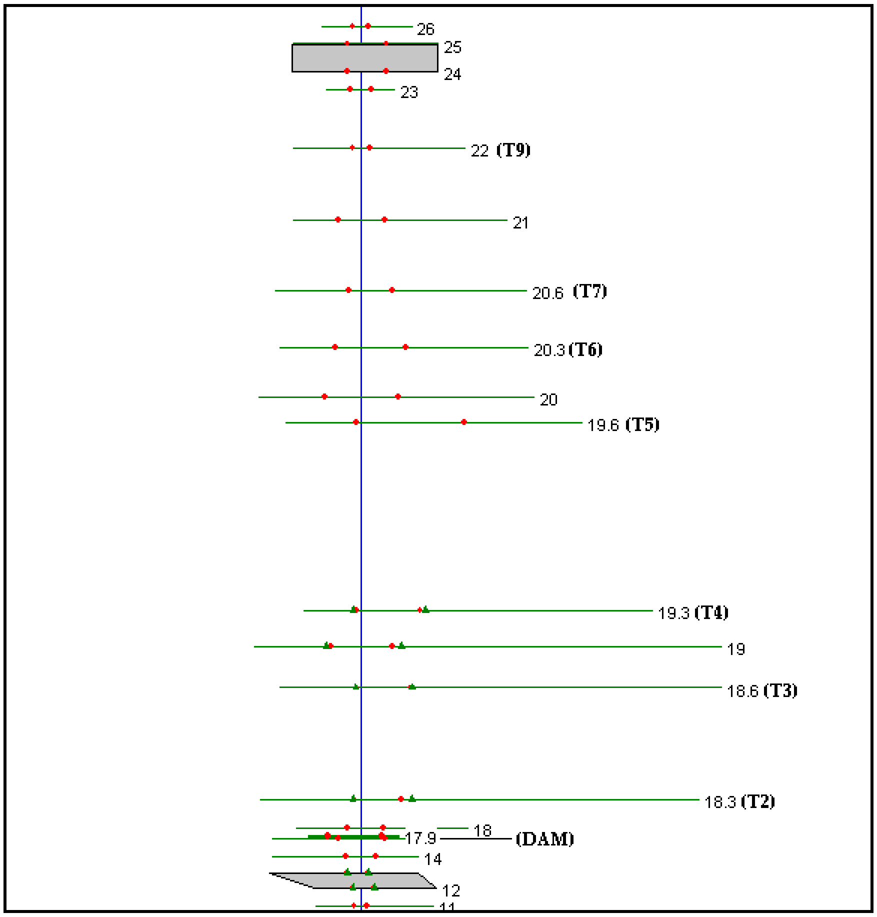
Stable particle size analyses were also compared with Hjulstrom's particle stability diagram. Turbulent conditions will dominate during high flood stage and at low flow conditions, due to influences from bed forms and materials. Laminar flow is very rare and unlikely due to bed materials and transitional flow is possible. Table 2 displays the stable particle sizes for a range of flows for each studied river transect for the two particle stability methods. Cross-section 18 is closest to the dam and 18.3 is transect #2 (see Figure 2). Cross-section 20.6 is furthest from the dam in the impoundment and is transect #7. Cross-section 22 is the first section above the impoundment and is transect #9.

Table 2: Comparison of Minimum Particle Size(mm) for Incipient Motion for 7Q10-Q100 by Shields and Hjulstrom with Dam Removed

X-sec	7Q10		Q1		Q2		Q10		Q100	
	D_s (mm)		D_s (mm)		D_s (mm)		D_s (mm)		D_s (mm)	
	Shields	Hjulstrom	Shields	Hjulstrom	Shields	Hjulstrom	Shields	Hjulstrom	Shields	Hjulstrom
22	4.42	2.20	51	17	131	>100	169	55	173	>100
20.6	0.00	0.00	1.26	1.1	11	10	23	16	44	23
19.6	37	9.20	25	9	13	8.9	13	8	20	13
19.3	0.00	2.10	5.06	4	28	15	41	16	22	16
18.3	0.00	0.00	0.63	0.9	16	9.1	34	18	74	27

Shield's and Hjulstrom's methods provide ranges of anticipated particle stability. In general Hjulstrom's method was the lower end of the size range. Table 3 shows the stable particle sizes for the range of considered flows. For some of the larger flows, while significant transport can be expected, the increasing depth of water limits the tractive force. For nearly every flow event at every cross-section, transport of coarse sands can be expected.

Figure 2: Location of Transects and Cross-Sections



Calculated stable particles will range from a coarse sand for the 7Q10 flows, to a coarse gravel for the annual flow, to large cobble for the Q2. This correlates with what was observed in the field. Field conditions above and below the impoundment observed bed armoring by bedrock overlain with gravel, cobble, and boulders. The bed armoring would be the result of the transport and removal of the particles below gravel size. Generally speaking, modeling efforts support the idea that the Q1.5-Q2 may be the channel forming events, and as such it is the point at which the combination of flood frequency and transport rates are the greatest. It is not the large infrequent events that result in significant bedload.

Particle stability analyses indicate that the sections above and below the impoundment are stable because they are armored. These sections are armored because particle stability exists for the common occurrence of flows less than bankfull discharge (Q1.5-Q2). However, materials within the impoundment can be expected to move across a range of flows. In addition, the bed slope can be expected to steepen as the sediment is removed, which will accelerate the process also leading to bank instability. These changes would reestablish sediment transport continuity and enable periodic flooding to purge the channel bed of fine sediments.

Bedload Sediment Transport

The selection of appropriate transport equations is important to predicting sediment loads in rivers. Yang (1996) and Simons (1992) review a wide range of transport equations. Given that the Merrimack Village Dam sediment is composed primarily of sand sized particle and larger, bedload transport equations are applicable for prediction of loads. For the Merrimack Village Dam, dry weight bedload rates were determined using Meyer-Peter and Müller (MPM) and Einstein-Brown (EB) methods to represent ranges of sediment bedload transport. MPM was developed in a boulder-bed mountain stream, and as such often over predicts smaller size particle transport in lower gradient streams. The EB method is more representative for sand size ranges. Bedload rates were determined by size fractions by Meyer-Peter and Müller and the Einstein-Brown method.

Meyer-Peter and Müller Bedload Transport Equation

Equation 2

$$q_{bw} = \left[\frac{\gamma R_H \left(\frac{k}{k'} \right)^{\frac{3}{2}} S_o - 0.047(\gamma_s - \gamma) D_m}{0.25 \rho^{\frac{1}{3}} \left(\frac{(\gamma_s - \gamma)}{\gamma} \right)^{\frac{2}{3}}} \right]^{\frac{3}{2}}$$

q_{bw}=dry weight bedload transport rate (lb/ft/sec)
D_s=particle size at incipient motion (mm)
τ_c= γRS=critical shear stress (lb/ft^2)
γ_s=specific weight of sediment (lb/ft^3)
γ_w=specific weight of water (lb/ft^3)
S_o= Bedslope
D_m= mean particle dimension (ft)
ρ= density (slug/ft^3)

Einstein-Brown Bedload Transport Equations

Equation 3

$$\tau_o = \gamma RS$$

Equation 4

$$\tau_* \frac{\tau_o}{(\gamma_s - \gamma) D_s}$$

Equation 5

$$F = \sqrt{2/3 + \frac{36\nu^2}{gD_s(\gamma_s/\gamma) - 1}} - \sqrt{\frac{36\nu^2}{gD_s(\gamma_s/\gamma) - 1}}$$

Equation 6

$$q_{bw} = \phi F \sqrt{g(\gamma_s - \gamma) D_s^{\,3}}$$

$\tau_c = \gamma RS$=critical shear stress (lb/ft^2)
τ_*= dimensionless shear stress
γ_w=specific weight of water (lb/ft^3)
γ_s=specific weight of sediment (lb/ft^3)
S_o= Bedslope
D_m= mean particle dimension (ft)
g= gravity (ft/s^2)
v=flow velocity
q_{bw}=dry weight bedload transport rate (lb/ft/sec)

Cross-section 18 is closest to the dam and 18.3 is transect #2. Cross-section 20.6 is furthest from the dam in the impoundment and3 is transect #7. Cross-section 22 is the first section above the impoundment and is transect #9.

Table 3: Transect #2 Bedload Transport Rates for Merrimack Village Dam

Return Period	**Flow**	**Einstein-Brown q_{bw}**	**Meyer-Peter and Muller q_{bw}**
(YRS)	(cfs)	(lb/ft/sec)	(lb/ft/sec)
7Q10 Flow	12.8	0.000	0.000
Mean Annual Flow	283	0.002	0.073
2YR Flood Flow	3140	0.198	6.981
10YR Flood Flow	6920	1.979	20.372
100YR Flood Flow	12500	1.979	66.008

Table 4: Transect #7 Bedload Transport Rates for Merrimack Village Dam

Return Period	**Flow**	**Einstein-Brown q_{bw}**	**Meyer-Peter and Muller q_{bw}**
(YRS)	(cfs)	(lb/ft/sec)	(lb/ft/sec)
7Q10 Flow	12.8	0.000	0.000
Mean Annual Flow	283	0.003	0.085
2YR Flood Flow	3140	1.614	3.855
10YR Flood Flow	6920	1.979	11.563
100YR Flood Flow	12500	1.979	29.919

Table 5: Transect #9 Bedload Transport Rates for Merrimack Village Dam

Return Period	**Flow**	**Einstein-Brown q_{bw}**	**Meyer-Peter and Muller q_{bw}**
(YRS)	(cfs)	(lb/ft/sec)	(lb/ft/sec)
7Q10 Flow	12.8	0.025	0.198
Mean Annual Flow	283	2.604	12.863
2YR Flood Flow	3140	4.797	68.800
10YR Flood Flow	6920	5.572	113.689
100YR Flood Flow	12500	1.979	106.513

Sediment Management Plan

Given the large volume of sediment within the impoundment, the preferred sediment management plan would be a gradual dewatering of the impoundment to allow for minimal erosion, minimal bank failure, and followed by vegetative stabilization of banks. Sediment stabilization should be possible, barring no large storm events, through vegetative stabilization of banks and sand deposits.

Considering the relatively uniform particle size distribution of sediments within the impoundment, it is probable that sediment transport will occur until the channel bed down cuts and reaches bedrock. No armoring is likely to occur due to the absence of large diameter particles because of the uniform sand-sized particle size distribution existing in the impoundment. The possible exception to the lack of armoring might occur if larger diameter particles (gravel size and up) were to be transported into the impoundment area during flow events greater than the Q1. This would result in a stratification of a top layer of more stable larger diameter particles. It is difficult to predict this process, but as this occurs, so will gradual armoring of the fine materials. Of course, prior to armoring, sediment transport will continue for the sand size particles and smaller. Table 6 illustrates the calculated annual sediment discharge based on the mean annual flow. These calculations are based on transport rates from transect #2, the last cross-section before exiting the impoundment. Due to location, this transect would be the rate limiting factor, meaning that the sediment load from the impoundment cannot exceed the rate at transect #2.

Table 6: Comparison of Methods Estimates for Mean Annual Sediment Discharge for Merrimack Village Dam

Einstein-Brown	Meyer-Peter and Muller
(tons)	(tons)
2,496	86,986

Hydraulics analyses indicate that sediment transport will be continuous for all ranges of flows except for the 7Q10. The current impoundment conditions prevent this from occurring due to lower velocities. The shallow depth to bedrock suggests that the pre-dam channel bed rested on scoured bedrock covered by migrating sand, gravel, and cobble. This assumption is supported by geomorphic investigations above and below the impoundment. This indicates that while initial channel development and subsequent sediment transport will occur, nick point migration will be limited by channel armoring from bedrock. Nick point migration refers to the process of streambed unraveling through down cutting. This occurs when there is no particle stability for the common occurrence of flows less than bankfull discharge. Nick point migration can move either up stream or down stream and can threaten bridge structures, bank stability, and locally lower groundwater tables. In this instance, channel down cutting is limited by bedrock. Geomorphic inspection also revealed that rapid lateral channel migration is unlikely due to channel entrenchment in bedrock. Investigations upstream of the impoundment revealed shallow depth to bedrock in channel banks. Specifically weathered bedrock with large boulder, cobble, and gravel existed above the thalweg.

Dewatering Process and Vegetative Stabilization

The gradual dewatering of the impoundment should occur at a rate not to exceed 0.5 ft/day to prevent bank failure. At the suggested rate of impoundment drawdown of 0.5 ft/day (the approximate hydraulic conductivity of the bank materials), with the maximum depth of approximately 8 feet, complete dewatering should take 16 days. This should be balanced with the need to minimize exposure of non-stabilized sediments. Bank failure is a function of slope material and material shear strength, slope angle, climate, vegetation and root density, water, and time. Each of these factors is important in controlling driving or resisting forces. The lowering of the water level removes a force resisting bank failure. Bank failure is more likely on steep slopes, common of channel banks. Channel banks also have dense root systems, however not always at depth. The amount of water in the soils increases driving forces and reduces friction resisting failure. High soil water content increases the driving force by adding to the total mass of the bank. Gradual dewatering enables the soils to drain at approximately the same rate as the drawdown, minimizing the soil mass.

Vegetative stabilization strategies should occur through either 1) the passive use of existing native seed beds in the impoundment deposits, or through 2) the active reseeding with native grasses and shrubs. Vegetative stabilization is currently ongoing in the backwater reaches of the impoundment on existing sand and point bars indicative of historical high water. Sensitive locations for suspected bank failure should be stabilized through a combination of the use of live-staking, coir fascine, and erosion control matting. Live-staking will provide for immediate stability by being driven into the channel banks and create long-term stability as rooting occurs. Coir fascine will provide immediate stability in high velocity flow regimes prior to vegetative root stabilization. Erosion control mats will also provide immediate stabilization and will protect sensitive emerging vegetation. The use of the live-staking, coir fascine, and erosion control matting is the crux to successful bank stabilization. It's use should not be overlooked where needed.

The targeting of active bank stabilization should follow channel development during the dewatering process. It is likely that the channel will continue to follow the existing thalweg initially. However as the channel begins to down cut and the bed slope increases, some channel migration is likely to occur to allow for increased sinuosity. To maximize channel stability and minimize preventable sediment transport, active bank stabilization should begin following initial channel development.

Sediment Management Summary

These hydraulic and sediment analyses don't evaluate flows within the receiving waters of the Merrimack River and in particular the ability of the river to transport the newly received sediment load. However, prior to the damming of the Souhegan River, the Merrimack River routinely received sediment loads, and the dam removal will only be restoring sediment transport continuity. The strategy of the dam removal and dewatering process should be directed such that the volume can be minimized though gradual dewatering and effective vegetative stabilization. The prevention of sedimentation of downstream habitat needs to be the goal. Fortunately, the sand size particles and larger are less harmful to aquatic microorganisms than siltation from smaller particles, which represent a small percentage (<10%) of that within the impoundment. Certainly, volumes of sediment will be transported to the receiving waters yet the exact amounts will be determined by the frequency and magnitude of flows in the months immediately following dam removal, and the success and method of vegetative stabilization.

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APPENDIX 1: CONSTANTS AND EQUATIONS FOR USE IN BEDLOAD TRANSPORT RATE CALCULATIONS

n=	0.03
k=	33.33333
k'=	40.12682
k/k'=	0.8307
γ= (pcf)	62.4
γs= (pcf)	165.36
ρ = (slug/ft3)	1.94
g= (ft/s2)	32.174

Meyer-Peter and Müller Bedload Transport Equation

Equation A1.1

$$q_{bw} = \left[\frac{\gamma R_H \left(\frac{k}{k'}\right)^{\frac{3}{2}} S_o - 0.047(\gamma_s - \gamma) D_m}{0.25 \rho^{\frac{1}{3}} \left(\frac{(\gamma_s - \gamma)}{\gamma}\right)^{\frac{2}{3}}} \right]^{\frac{3}{2}}$$

Einstein-Brown Bedload Transport Equation

Equation A1.2

$$\tau_o = \gamma RS$$

Equation A1.3

$$\tau_* \frac{\tau_o}{(\gamma_s - \gamma) D_s}$$

Equation A1.4

$$F = \sqrt{2/3 + \frac{36\nu^2}{gD_s(\gamma_s/\gamma) - 1}} - \sqrt{\frac{36\nu^2}{gD_s(\gamma_s/\gamma) - 1}}$$

EquationA1.5

$$q_{bw} = \phi F \sqrt{g(\gamma_s - \gamma) D_s^{\ 3}}$$

EquationA1.5 $$Q_s = q_{bw} 0.9 B_t T$$

Q_s=sediment discharge for entire stream cross-section (tons/year)
q_{bw}=dry weight bedload transport rate (lb/ft/sec)
B_t= cross-section top width (ft)
T= time, duration (seconds/year)

APPENDIX 2: TRANSECT #2 BEDLOAD TRANSPORT CALCULATIONS BY MEYER-PETER AND MÜLLER METHOD

Transect 2 Sediment Transport by Size Fraction for 7Q10 Year Flood, Q=12.8 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	q_{bw} (lb/ft/sec)
100	2						
		1.341641	0.15	0.201246	0.00066	-0.02334	#NUM!
85	0.9						
		0.391152	0.35	0.136903	0.000449	-0.01588	#NUM!
50	0.17						
		0.055317	0.35	0.019361	6.35E-05	-0.00225	#NUM!
15	0.018						
		0.002683	0.15	0.000402	1.32E-06	-4.7E-05	#NUM!
0	0.0004						
		$D_m=\Sigma d_{ave}p_i$(mm)		0.357913	0.001174	Σqbw	0

Transect 2 Sediment Transport by Size Fraction for Mean Annual Flood, Q=283 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	q_{bw} (lb/ft/sec)
100	2						
		1.341641	0.15	0.201246	0.00066	0.056136	0.0133005
85	0.9						
		0.391152	0.35	0.136903	0.000449	0.063599	0.0160389
50	0.17						
		0.055317	0.35	0.019361	6.35E-05	0.077232	0.0214632
15	0.018						
		0.002683	0.15	0.000402	1.32E-06	0.079431	0.0223862
0	0.0004						
		$D_m=\Sigma d_{ave}p_i$(mm)		0.357913	0.001174	Σqbw	0.07318883

Transect 2 Sediment Transport by Size Fraction for 2 Year Flood, Q=3140 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	q_{bw} (lb/ft/sec)
100	2						
		1.341641	0.15	0.201246	0.00066	1.43653	1.7217584
85	0.9						
		0.391152	0.35	0.136903	0.000449	1.443993	1.7351923
50	0.17						
		0.055317	0.35	0.019361	6.35E-05	1.457626	1.759823
15	0.018						
		0.002683	0.15	0.000402	1.32E-06	1.459824	1.7638065
0	0.0004						

		$D_m = \Sigma d_{ave} p_i$(mm)		0.357913	0.001174	Σqbw	6.98058019

Transect 2 Sediment Transport by Size Fraction for 10 Year Flood, Q=8370 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	$q_{bw\ (lb/ft/sec)}$
100	2						
		1.341641	0.15	0.201246	0.00066	2.947164	5.0594858
85	0.9						
		0.391152	0.35	0.136903	0.000449	2.954626	5.0787147
50	0.17						
		0.055317	0.35	0.019361	6.35E-05	2.968259	5.1139051
15	0.018						
		0.002683	0.15	0.000402	1.32E-06	2.970458	5.1195886
0	0.0004						
		$D_m = \Sigma d_{ave} p_i$(mm)		0.357913	0.001174	Σqbw	20.3716942

Transect 2 Sediment Transport by Size Fraction for 100 Year Flood, Q=15120 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	$q_{bw\ (lb/ft/sec)}$
100	2						
		1.341641	0.15	0.201246	0.00066	6.468783	16.452576
85	0.9						
		0.391152	0.35	0.136903	0.000449	6.476246	16.481054
50	0.17						
		0.055317	0.35	0.019361	6.35E-05	6.489879	16.533121
15	0.018						
		0.002683	0.15	0.000402	1.32E-06	6.492077	16.541524
0	0.0004						
		$D_m = \Sigma d_{ave} p_i$(mm)		0.357913	0.001174	Σqbw	66.0082762

APPENDIX 3: TRANSECT #7 BEDLOAD TRANSPORT CALCULATIONS BY MEYER-PETER AND MÜLLER METHOD

Transect 7 Sediment Transport by Size Fraction for 7Q10 Year Flood, Q=12.8 cfs by Meyer, Peter, & Muller

%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	q_{bw} (lb/ft/sec)
100	2						
		1.48324	0.15	0.222486	0.00073	-0.02473	#NUM!
85	1.1						
		0.637966	0.35	0.223288	0.000733	-0.02482	#NUM!
50	0.37						
		0.201742	0.35	0.07061	0.000232	-0.00711	#NUM!
15	0.11						
		0.006633	0.15	0.000995	3.26E-06	0.000961	2.98E-05
0	0.0004						
		$D_m=\Sigma d_{ave}p_i$(mm)		0.517379	0.001697	Σqbw	0

Transect 7 Sediment Transport by Size Fraction for Mean Annual Flood, Q=283 cfs by Meyer, Peter, & Muller

%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	q_{bw} (lb/ft/sec)
100	2						
		1.48324	0.15	0.222486	0.00073	0.065373	0.016715
85	1.1						
		0.637966	0.35	0.223288	0.000733	0.06528	0.016679
50	0.37						
		0.201742	0.35	0.07061	0.000232	0.082988	0.023907
15	0.11						
		0.006633	0.15	0.000995	3.26E-06	0.091062	0.027479
0	0.0004						
		$D_m=\Sigma d_{ave}p_i$(mm)		0.517379	0.001697	Σqbw	0.0847798

Transect 7 Sediment Transport by Size Fraction for 2 Year Flood, Q=3140 cfs by Meyer, Peter, & Muller

%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	q_{bw} (lb/ft/sec)
100	2						
		1.48324	0.15	0.222486	0.00073	0.964824	0.947703
85	1.1						
		0.637966	0.35	0.223288	0.000733	0.964731	0.947566
50	0.37						
		0.201742	0.35	0.07061	0.000232	0.982439	0.973774
15	0.11						
		0.006633	0.15	0.000995	3.26E-06	0.990513	0.985803
0	0.0004						
		$D_m=\Sigma d_{ave}p_i$(mm)		0.517379	0.001697	Σqbw	3.8548464

Transect 7 Sediment Transport by Size Fraction for 10 Year Flood, Q=8370 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	$q_{bw\ (lb/ft/sec)}$
100	2						
		1.48324	0.15	0.222486	0.00073	2.018463	2.867684
85	1.1						
		0.637966	0.35	0.223288	0.000733	2.01837	2.867486
50	0.37						
		0.201742	0.35	0.07061	0.000232	2.036078	2.905305
15	0.11						
		0.006633	0.15	0.000995	3.26E-06	2.044152	2.922603
0	0.0004						
		$D_m=\Sigma d_{ave}p_i$(mm)		0.517379	0.001697	Σqbw	11.563078

Transect 7 Sediment Transport by Size Fraction for 100 Year Flood, Q=15120 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	$q_{bw\ (lb/ft/sec)}$
100	2						
		1.48324	0.15	0.222486	0.00073	3.813869	7.448155
85	1.1						
		0.637966	0.35	0.223288	0.000733	3.813776	7.447883
50	0.37						
		0.201742	0.35	0.07061	0.000232	3.831484	7.499815
15	0.11						
		0.006633	0.15	0.000995	3.26E-06	3.839558	7.523534
0	0.0004						
		$D_m=\Sigma d_{ave}p_i$(mm)		0.517379	0.001697	Σqbw	29.919386

APPENDIX 4: TRANSECT #9 BEDLOAD TRANSPORT CALCULATIONS BY MEYER-PETER AND MÜLLER METHOD

Transect 9 Sediment Transport by Size Fraction for 7Q10 Year Flood, Q=12.8 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	$q_{bw\ (lb/ft/sec)}$
100	1000						
		707.1068	0.15	106.066	0.347986	-11.911	#NUM!
85	500						
		264.5751	0.35	92.6013	0.30381	-10.3493	#NUM!
50	140						
		48.78524	0.35	17.07484	0.05602	-1.58966	#NUM!
15	17						
		2.915476	0.15	0.437321	0.001435	0.339973	0.19822872
0	0.5						
		$D_m=\Sigma d_{ave}p_i$(mm)		216.1795	0.70925	Σqbw	0.198228723

Transect 9 Sediment Transport by Size Fraction for Mean Annual Flood, Q=283 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	$q_{bw\ (lb/ft/sec)}$
100	1000						
		707.1068	0.15	106.066	0.347986	-7.89632	#NUM!
85	500						
		264.5751	0.35	92.6013	0.30381	-6.33467	#NUM!
50	140						
		48.78524	0.35	17.07484	0.05602	2.424974	3.77624957
15	17						
		2.915476	0.15	0.437321	0.001435	4.354612	9.08707569
0	0.5						
		$D_m=\Sigma d_{ave}p_i$(mm)		216.1795	0.70925	Σqbw	12.86332525

Transect 9 Sediment Transport by Size Fraction for 2 Year Flood, Q=3140 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	$q_{bw\ (lb/ft/sec)}$
100	1000						
		707.1068	0.15	106.066	0.347986	-0.79941	#NUM!
85	500						
		264.5751	0.35	92.6013	0.30381	0.762245	0.66549106
50	140						
		48.78524	0.35	17.07484	0.05602	9.521889	29.3822227
15	17						
		2.915476	0.15	0.437321	0.001435	11.45153	38.7520827
0	0.5						
		$D_m=\Sigma d_{ave}p_i$(mm)		216.1795	0.70925	Σqbw	68.79979642

Transect 9 Sediment Transport by Size Fraction for 10 Year Flood, Q=8370 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	$q_{bw\ (lb/ft/sec)}$
100	1000						
		707.1068	0.15	106.066	0.347986	2.438616	3.80815922
85	500						
		264.5751	0.35	92.6013	0.30381	4.000269	8.00080789
50	140						
		48.78524	0.35	17.07484	0.05602	12.75991	45.5797086
15	17						
		2.915476	0.15	0.437321	0.001435	14.68955	56.3005626
0	0.5						
		$D_m=\Sigma d_{ave}p_i$(mm)		216.1795	0.70925	Σqbw	113.6892384

Transect 9 Sediment Transport by Size Fraction for 100 Year Flood, Q=15120 cfs by Meyer, Peter, & Muller							
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	$q_{bw}^{2/3}$	$q_{bw\ (lb/ft/sec)}$
100	1000						
		707.1068	0.15	106.066	0.347986	2.852617	4.81798156
85	500						
		264.5751	0.35	92.6013	0.30381	4.41427	9.27445413
50	140						
		48.78524	0.35	17.07484	0.05602	13.17391	47.8158855
15	17						
		2.915476	0.15	0.437321	0.001435	15.10355	58.6973628
0	0.5						
		$D_m=\Sigma d_{ave}p_i$(mm)		216.1795	0.70925	Σqbw	106.5132483

APPENDIX 5: TRANSECT #2 BEDLOAD TRANSPORT CALCULATIONS BY EINSTEIN-BROWN METHOD

Transect 2 Sediment Transport by Size Fraction for 7Q10 Year Flood, Q=12.8 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	0.0000	0	0.0000
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	0.0000	0	0.0000
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	0.0000	0	0.0000
15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	0.0000	0	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	0.0000

Transect 2 Sediment Transport by Size Fraction for Mean Annual Flood, Q=283 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	0.1912	0.28	0.0003
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	0.1905	0.28	0.0003
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	0.6025	10	0.0016
15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	42.7533	1000	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	0.0021

Transect 2 Sediment Transport by Size Fraction for 2 Year Flood, Q=3140 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	3.5120	100	0.0909
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	3.4994	100	0.0914
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	11.0661	100	0.0156

15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	785.3106	1000	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	0.1979

Transect 2 Sediment Transport by Size Fraction for 10 Year Flood, Q=8370 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	7.1462	1000	0.9089
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	7.1205	1000	0.9139
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	22.5169	1000	0.1558
15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	1597.9278	1000	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	1.9786

Transect 2 Sediment Transport by Size Fraction for 100 Year Flood, Q=15120 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	15.6181	1000	0.1909
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	15.5620	1000	0.1919
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	49.2114	1000	0.1558
15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	3492.3178	1000	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	1.9786

APPENDIX 6: TRANSECT #7 BEDLOAD TRANSPORT CALCULATIONS BY EINSTEIN-BROWN METHOD

Transect 7 Sediment Transport by Size Fraction for 7Q10 Year Flood, Q=12.8 cfs by Einstein-Brown Method

%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.3416	0.2	0.2012	0.0007	0.7991	0.0029	0	0.0000
85	0.9								
		0.3912	0.4	0.1369	0.0004	0.7911	0.0042	0	0.0000
50	0.17								
		0.0553	0.4	0.0194	0.0001	0.6539	0.0298	0	0.0000
15	0.018								
		0.0027	0.2	0.0004	0.0000	0.0378	1.4320	230	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.3579	0.0012			Σqbw	0.0000

Transect 7 Sediment Transport by Size Fraction for Mean Annual Flood, Q=283 cfs by Einstein-Brown Method

%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	0.2193	0.33	0.0003
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	0.2186	0.33	0.0003
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	0.6911	17	0.0026
15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	49.0471	1000	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	0.0033

Transect 7 Sediment Transport by Size Fraction for 2 Year Flood, Q=3140 cfs by Einstein-Brown Method

%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	2.3832	800	0.7271
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	2.3746	800	0.7311
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	7.5091	1000	0.1558

15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	532.8901	1000	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	1.6141

Transect 7 Sediment Transport by Size Fraction for 10 Year Flood, Q=8370 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	4.9179	1000	0.9089
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	4.9002	1000	0.9139
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	15.4959	1000	0.1558
15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	1099.6758	1000	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	1.9786

Transect 7 Sediment Transport by Size Fraction for 100 Year Flood, Q=15120 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	9.2371	1000	0.9089
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	9.2039	1000	0.9139
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	29.1054	1000	0.1558
15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	2065.4812	1000	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	1.9786

APPENDIX 7: TRANSECT #9 BEDLOAD TRANSPORT CALCULATIONS BY EINSTEIN-BROWN METHOD

Transect 9 Sediment Transport by Size Fraction for 7Q10 Year Flood, Q=12.8 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	1000								
		707.1068	0.2	106.0660	0.3480	0.8165	0.0020	0	0.0000
85	500								
		264.5751	0.4	92.6013	0.3038	0.8165	0.0023	0	0.0000
50	140								
		48.7852	0.4	17.0748	0.0560	0.8163	0.0122	0	0.0000
15	17								
		2.9155	0.2	0.4373	0.0014	0.8084	0.4782	10	0.0253
0	0.5								
		$D_m=\Sigma d_{ave}p_i$(mm)		216.1795	0.7093			Σqbw	0.0253

Transect 9 Sediment Transport by Size Fraction for Mean Annual Flood, Q=283 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	1000								
		707.1068	0.2	106.0660	0.3480	0.8165	0.0222	0	0.0000
85	500								
		264.5751	0.4	92.6013	0.3038	0.8165	0.0255	0	0.0000
50	140								
		48.7852	0.4	17.0748	0.0560	0.8163	0.1381	0.12	0.0748
15	17								
		2.9155	0.2	0.4373	0.0014	0.8084	5.3917	1000	2.5288
0	0.5								
		$D_m=\Sigma d_{ave}p_i$(mm)		216.1795	0.7093			Σqbw	2.6036

Transect 9 Sediment Transport by Size Fraction for 2 Year Flood, Q=3140 cfs by Einstein-Brown Method									
%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	1000								
		707.1068	0.2	106.0660	0.3480	0.8165	0.0580	0.01	0.0482
85	500								
		264.5751	0.4	92.6013	0.3038	0.8165	0.0665	0.01	0.0393
50	140								
		48.7852	0.4	17.0748	0.0560	0.8163	0.3606	3.5	2.1803
15	17								

		2.9155	0.2	0.4373	0.0014	0.8084	14.0775	1000	2.5288
0	0.5								
		$D_m=\Sigma d_{ave}p_i$(mm)		216.1795	0.7093			Σqbw	4.7967

Transect 9 Sediment Transport by Size Fraction for 10 Year Flood, Q=8370 cfs by Einstein-Brown Method

%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	1000								
		707.1068	0.2	106.0660	0.3480	0.8165	0.0744	0.02	0.1447
85	500								
		264.5751	0.4	92.6013	0.3038	0.8165	0.0852	0.02	0.1574
50	140								
		48.7852	0.4	17.0748	0.0560	0.8163	0.4621	4.4	2.7409
15	17								
		2.9155	0.2	0.4373	0.0014	0.8084	18.0405	1000	2.5288
0	0.5								
		$D_m=\Sigma d_{ave}p_i$(mm)		216.1795	0.7093			Σqbw	5.5718

Transect 9 Sediment Transport by Size Fraction for 100 Year Flood, Q=15120 cfs by Einstein-Brown Method

%Passing	di(m)	d_{ave}(mm)	p_i	$d_{ave}p_i$(mm)	$d_{ave}p_i$(ft)	Fi	τ_{*i}	Φ	$(g_b)_I$ (lb/sec/ft)
100	2								
		1.4832	0.2	0.2225	0.0007	0.8007	36.4567	1000	0.9089
85	1.1								
		0.6380	0.4	0.2233	0.0007	0.8008	36.3257	1000	0.9139
50	0.37								
		0.2017	0.4	0.0706	0.0002	0.7679	114.8720	1000	0.1558
15	0.11								
		0.0066	0.2	0.0010	0.0000	0.0925	8151.9597	1000	0.0000
0	4E-04								
		$D_m=\Sigma d_{ave}p_i$(mm)		0.5174	0.0017			Σqbw	1.9786